International Journal of Electrical and Electronics
Engineering Research (IJEEER)
ISSN(P): 2250-155X; ISSN(E): 2278- 943X
Vol. 5, Issue 5, Oct 2015, 71-84

AN INSIGHT INTO FLY BACK CONVERTER FOR VARIOUS APPLICATIONS

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ABSTRACT

A Fly back converter is nothing but an isolated DC-DC converter. The applications where this fly back converter can be efficiently used are discussed in this paper. Fly back converter has a number of advantages which makes it suitable for a number of low power applications (<200W) such as LED lighting, SMPS applications, areas where multiple output is required, Power factor correction techniques and in CCD applications. The major advantage of Fly back converter when compared to other isolated topologies is its simplicity as only few components are required. Also the output side inductor is not required.

KEYWORDS: SMPS (Switched Mode Power Supply), LED (Light Emitting Diode), Cross Regulation

INTRODUCTION

A Fly back converter can be used in areas of ac-dc and dc-dc conversion with isolation provided between the input and output side of the transformer. It is more fault tolerant than other isolated non-transformer topologies. Fly back converter is one of the simplest isolated dc-dc converters because of the absence of output side inductor and the presence of only one switch and a transformer. The transient response of the fly back converter is also fast because of the absence of inductor at the output side filter. It can be used in applications where multiple outputs are required from a single transformer. Though the fly back converter has several advantages, it has certain disadvantages such as the output side current ripple is high and also the cross regulation in the case of multiple outputs are generally high. These disadvantages can be overcome if certain other devices are added to the primary side but the main advantage of simplicity and low cost is lost. So it can be used in areas where cross regulation and high ripple current is not a concern. Due to the high ripple current, the fly back converter is less efficient when compared to other topologies for high power applications. So Fly back converter is suitable for areas where low power is required.

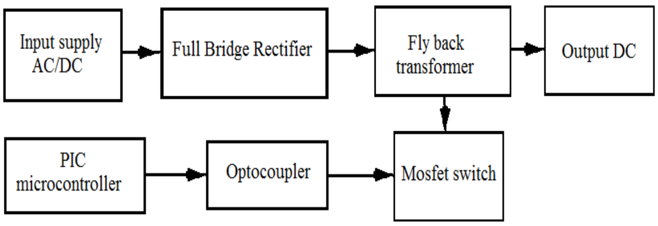

Figure 1: Functional Block Diagram of Fly Back Converter

The input can be AC or DC. If the input is AC, a full bridge rectifier must be used to rectify the alternating input. The simple capacitor is used as a filter in the output side to avoid ripples in the output. When the gate pulse is given to the main switch, it is turned on and the transformer stores energy. At this stage, the output side diode is reverse biased. The

stored energy in the output capacitor discharges to the load. And when the gate pulse is low, the main switch is turned off and the output diode is forward biased and so the output capacitor stores energy which is then dissipated in the load.

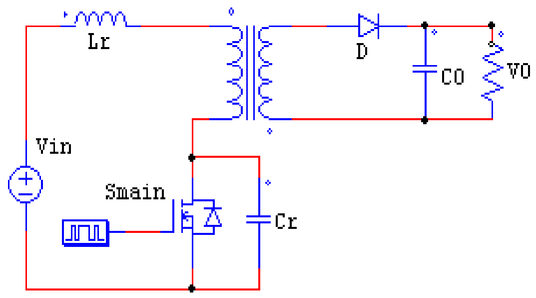

Figure 2: General Structure of Fly Back Converter

The functional block diagram is shown in Figure 1 and its general structure in Figure 2. When the output side is considered, the secondary side diode is found to be in series with the inductance. This means that no filter inductance is required for fly back converter, only the filter capacitor is sufficient. This advantage makes the fly back converter suitable for multiple output supplies as the size and cost of the output side filter is very much reduced.

One of the main disadvantages of fly back converter is that all the output power transferred has to be stored in the core, thus increasing the size and cost of the core much greater than other isolated topologies where the core excitation energy alone is stored which is comparatively very small. Thus in addition to the poor core utilization, the transformer size is also bulky. This disadvantage can be overcome by storing sufficiently high stored energy. For ensuring this high stored energy, the primary inductance of the fly back converter must be significantly lower than the inductance required for the transformer. Another disadvantage is that when the main switch is turned off, the transferred energy will be reflected back into the primary through the transformer. In many cases, the reflected energy may be as high as the supply voltage, this in turn will lead to the voltage spike at main switch turn off. The only way to remove this voltage spike is to add clamping techniques [5] in the primary side so that the reflected energy may be recycled without stressing the main switch.

FLY BACK CONVERTER FOR HIGH POWER FACTOR APPLICATIONS

Here the three phase ac-dc converter with resonant snubber circuit for a discontinuous current mode (DCM) of fly back converter is discussed to obtain high power factor at the input side and high quality dc voltage at the output side. Since high power factor is obtained at the input side, the switching loss across the components is very much reduced. Regarding the components of the proposed converter, it consists of 6 fast recovery diodes at the primary side,3 diodes at the secondary side,1 primary switch S1,an output capacitor C0 and the inputs of the converter can be connected directly to the utility through a low pass LC filter as shown in Figure 3.The operation of this proposed converter can be seen from in [1].

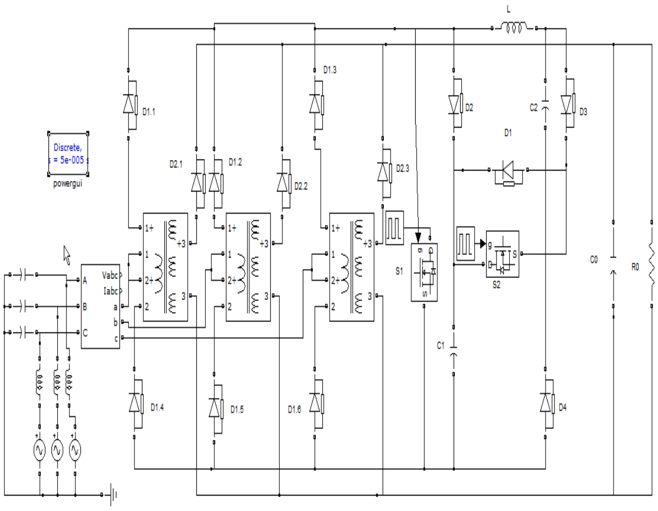

Figure 3: Simulink Diagram of 3 Phase Fly Back Converter with Resonant Snubber Circuit

POWER FACTOR ANALYSIS

When the main switch is switched on, the magnetizing current of phase A rises from zero to a peak value at the end of a switching cycle (i.e.,) at DT_s.The current increases with a slope of $\frac{V_a}{L_p}$ and so the expression of current at the primary winding can be given by,

$$i_a = \frac{V_a}{L_p} t \quad (1)$$

Where the value of V_a must be constant for a single switching cycle and L_p represents the primary side inductance of the fly back transformer and is given by the equation,

$$L_p = \frac{3}{4} {V_m}^2 \frac{T_s}{P_{0(max)}} {D_{max}}^2 \quad (2)$$

Where $P_{0(max)}$ is the maximum value of the output power and D_{max} is the maximum duty ratio of the main switch S1.The expression of peak value of magnetizing current at the end of switching cycle (i.e.,) DT_s can be given as,

$$i_{a(max)} = \frac{V_a}{L_p}(DT_s) \quad (3)$$

Where $V_a = V_m \sin wt$ is the instantaneous phase voltage of the source. And so the equation becomes,

$$i_{a(max)} = \frac{V_m \sin wt}{L_p}(DT_s) \quad (4)$$

From equation (4), it can be seen that the peak of the magnetizing current that is occurring for each switching cycle will change according to the instantaneous phase value of source voltage. Since the input phase voltage is sinusoidal,

the peak value of magnetizing current must follow the input voltage and hence it is also be sinusoidal. The average value of input current in phase A is given as follows,

$$I_{a(avg)} = \frac{1}{T_s}\int_0^{DT_s} \frac{V_a}{L_p} tdt \tag{5}$$

At any time, the average current can be given as below,

$$I_{a,avg(t)} = \frac{V_m D^2 T_s}{2L_p} \sin wt \tag{6}$$

Where D represents the duty cycle of the main switch S1, T_p represents the time period of a switching cycle. Equation 5 shows how a high power factor is obtained. In equation 6, the term $\frac{V_m D^2 T_s}{2L_p}$ is constant and hence implying the instantaneous average current is also sinusoidal and it will be in in-phase with the supply phase voltage.

SIMULATION RESULTS

The simulation was carried out under 10 kHz for the proposed converter and the duty cycle of the main switch S1 was given as 0.4.The main advantage of this ac-dc fly back converter with resonant snubber circuit is that in phase voltage and current (i.e.,) high power factor and a high quality dc output voltage is obtained which in shown in Figure 4 and 6.

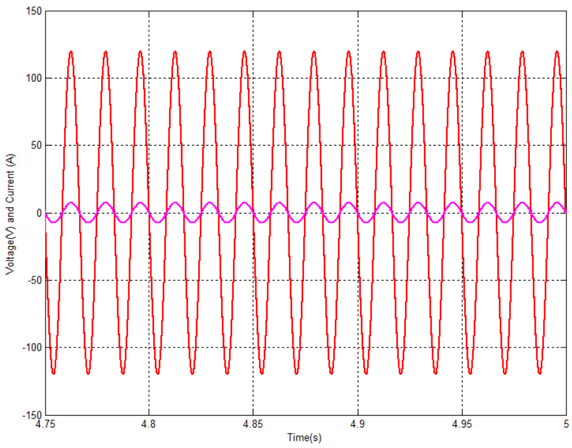

Figure 4: In-Phase Voltage and Current

The FFT analysis results for proposed converter is shown in figure 5 and the total harmonic distortion is found to be only 2.24% which is a notable advantage .The power factor is calculated using the following formulae and is found to be 0.9489 (near unity power factor).

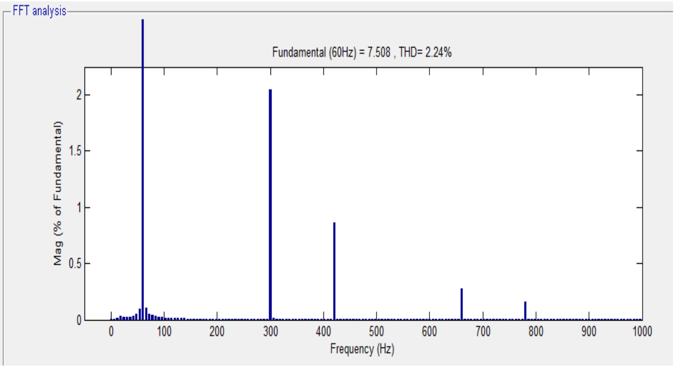

Figure 5: FFT Analysis (THD=2.24%)

Displacement power factor (DPF) = Cos θ

Where θ = ωt

Displacement factor (DF) =1/sq.rt(1+THD^2)

Power Factor (PF) = DPF*DF

Here, Power factor obtained is 0.9489 (near unity power factor).

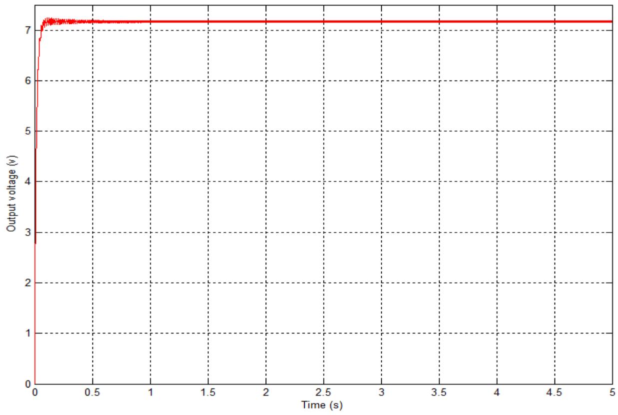

Figure 6: High Quality DC Output Voltage

Thus the topology of fly back converter for high power factor applications is discussed above. In addition to this advantage, the proposed resonant snubber circuit reduces the stress across the switching components.

FLY BACK CONVERTER FOR LED LIGHTING APPLICATIONS

Nowadays, LEDs find many applications such as automotive taillights, LCD backlights, traffic signals, street lights and electronic signs.The proposed active clamped fly back converter has its wide applications in LED lighting systems with PV as source also as shown in Figure 7.Here, the proposed fly back converter can be used as a discharger to drive the LEDs in traffic signals or street lights or any other lighting applications. Any buck boost converter can be used for charging the battery. The requirement of both low power and low voltage s satisfied by this converter even without the risk of extreme duty ratios. This point is to be noted as high duty ration may increase the losses and the size of the output side capacitor.

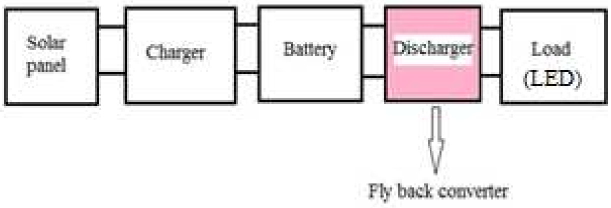

Figure 7: Application of Fly Back Converter in LED Lighting

ACTIVE CLAMPED FLY BACK CONVERTER

The proposed active clamped Fly back converter consists of a fly back transformer, a main switch Smain, resonant capacitor Cr and inductor Lr and a output diode D0.The energy is stored when the main switch is on and transferred to the secondary side when the main switch is turned off. This stored energy must be recycled before the next turn on of main switch, for this purpose clamping is done. There are types of clamping techniques such as RCD clamping, transistorized clamping and active clamping. The active clamping seems to provide less voltage and current stress across the components than the other two clamping techniques [5] and hence active clamping is employed here. The proposed active clamping circuit consists of a auxiliary switch Saux and a Clamp capacitor Cclamp and is shown in Figure 8.

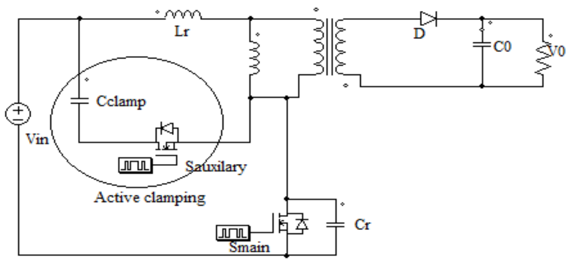

Figure 8: Active Clamped Fly Back Converter for LED Lighting

SIMULATION PARAMETERS AND RESULTS

The simulation parameters of active clamped fly back converter are given below: Switching frequency is 100 kHz, resonant capacitor and inductor is 1.5nF and 17µF respectively. If the input voltage is in the range of 90 to 130 V, then the output voltage will be in the range of 10 to 15 V. Here the maximum duty cycle of main switch is 0.45 and is given by the equation (7).

$$D = \frac{V_{out} * \frac{N_{pri}}{N_{sec}}}{V_{in} + V_{out} * \frac{N_{pri}}{N_{sec}}} \tag{7}$$

The design parameters of this proposed converter are as follows,

$$n = \frac{N1}{N2} = \frac{\text{Vin min}}{\text{V0}} \frac{\text{Dmax}}{1-\text{Dmax}} \tag{8}$$

Where n is the turns ration of the fly back transformer, N1 and N2 are the number of turns in the primary and secondary side of the transformer.

On simulating the proposed converter, it is seen that the efficiency change is very small around 85% for the load ranging from 10 to 50 W, which will generally be the requirement for a LED load. And also the voltage stress of the switches is also minimum for this load range justifying the choice of active clamped fly back converter for LED applications [5].And the output side diodes may be replaced by a fifth generation component such as Synchronous rectifier (SR) as it has low on state resistance and hence low voltage drop for the betterment of efficiency. An average improvement in efficiency of 7% was obtained when the diodes were replaced by SR[5]. The pulse for Main and auxiliary switch is given in Figure 9.The output current of this proposed converter is shown in Figure 10.

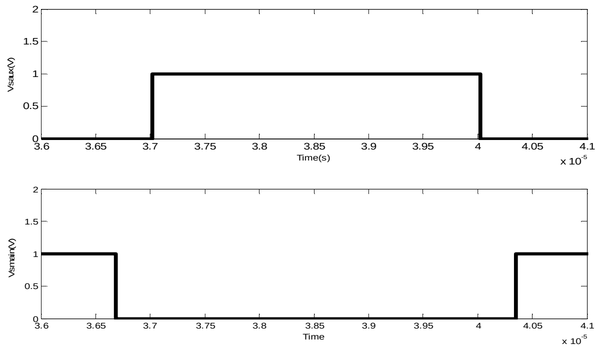

Figure 9: Pulse Pattern of Auxiliary and Main Switch

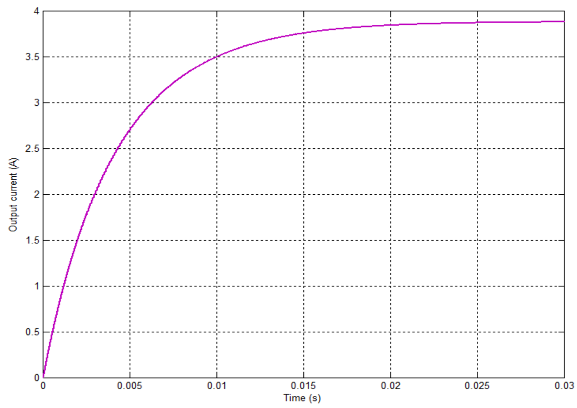

Figure 10: Output Current of Proposed Converter

A 30 W LED will be sufficient for street lighting applications as it is found to be equivalent to 105 W incandescent bulb. This active clamped Fly back converter is found suitable for this applications with a maximum efficiency of 88.32% [5] and minimum voltage stress.

FLY BACK CONVERTER FOR MULTIPLE OUTPUT APPLICATIONS

The Fly back converter will be a suitable choice for multiple output applications, where multiple stabilized outputs are required from a single input supply. The number of outputs required is proportional to the number of secondary windings in the fly back transformer. So any additional output will require only another output capacitor and a secondary winding. Here only one output voltage will be regulated and other output voltages will be regulated through transformer

actions. So perfect coupling between the windings will be required to define the output voltage by the turns ratio of the transformer. But practically, perfect coupling between the windings is impossible leading to poor cross regulation.

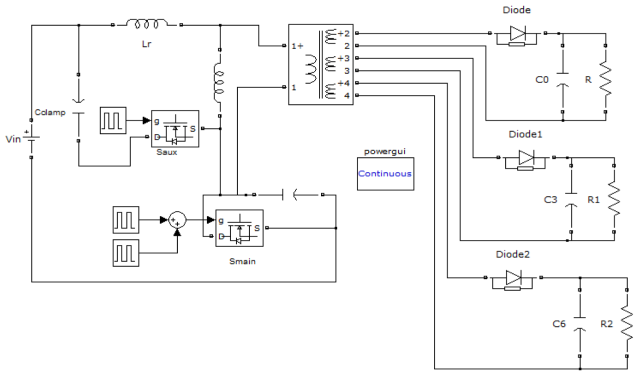

Figure 11: Simulink Diagram of Multi Winding Fly Back Converter

Cross regulation is one of the serious limitations faced by the multi winding fly back converter. The energy will be stored in the fly back transformer during the on time. As seen earlier, the input current will reach its peak at the end of switching cycle (i.e.,) Ton. This current will be transferred to the secondary winding and this is not a problem in the case of single winding fly back transformer. The cross regulation can be understood by observing the sharing of transferred current between the secondaries. It is observed that majority of the current is transferred to the winding with minimum leakage inductance. If this transferred output is given as a feedback for controlling the pulse, then the output of other secondary windings will also gets reduced. The solution to improve this cross regulation, external inductors must be added as shown in Figure 12.By doing so, the rate of change of current in all the three windings will be same, so that the peaking of current can be avoided or minimized.

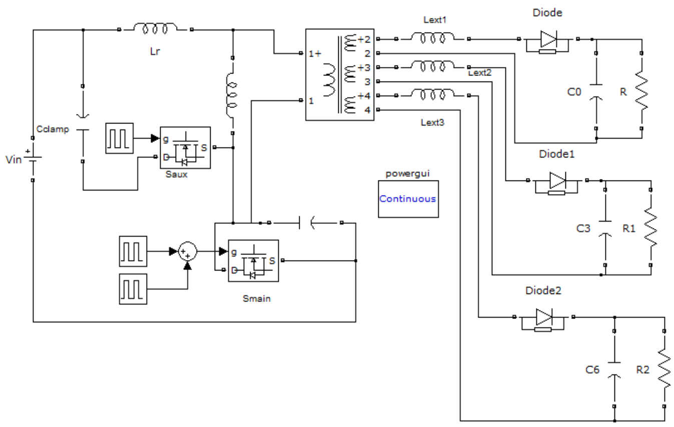

Figure 12: Multi Winding Fly Back Converter with External Inductance to Overcome Cross Regulation

Considering only two secondary winding, then the value of external inductance value connected can be found from the equation given below,

$$L_{ext2} = \left(\frac{N_{s1}}{N_{s2}}\right)^2 L_{ext1} \quad (9)$$

Where L_{ext1} and L_{ext2} are the external inductance connected to the winding s_1 and s_2 on the secondary side. Similarly N_{S1} andN_{S2} are the number of windings of the secondary windings of the fly back transformer.

SIMULATION RESULTS

The simulations were carried out with active clamped multiple output fly back converter. The turns ratio of the multi winding fly back transformer have to be selected depending upon the application. Here multiple outputs were obtained for 5.2V, 10.8V, 16V and is shown in Figure 13. This proposed converter has the advantage of high efficiency and most importantly small solution size. It is applicable for low and medium power applications such as Power Over Ethernet (POE) devices.

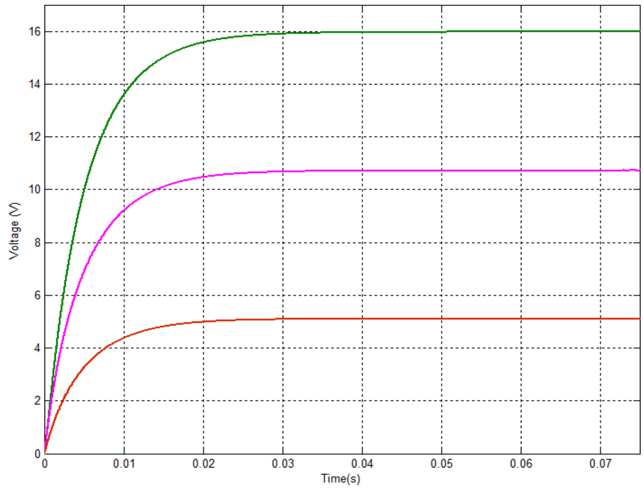

Figure 13: Multiple Output Voltages of Proposed Converter

FLY BACK CONVERTER FOR SMPS APPLICATION

Linear power supplies have been used initially, but it has a disadvantage of very poor power conversion efficiencies of about 30%.This disadvantage is overcome by using Switched Mode Power Supplies (SMPS) whose standard efficiency will be about 70% to 80%.As high switching frequencies are employed, the size of the output side filter components is very much reduced when compared to the linear power supply. Thus an efficient SMPS design can produce light weight and compact supplies. Uninterruptible power supply must be used nowadays, in order to protect the voltage sensitive devices and to avoid the loss of important data’s due to power failure. The computer SMPS and external UPS has been integrated in the proposed converter as shown in Figure 13, to provide uninterruptible power.

The proposed integrated converter has two input power (i.e.,) V_{ac} and V_b. V_b must be a low voltage battery back-up. This proposed converter will operate in three modes of operation as normal mode, charging mode and switching mode. The switch shown in Figure 14 will decide the mode of operation.

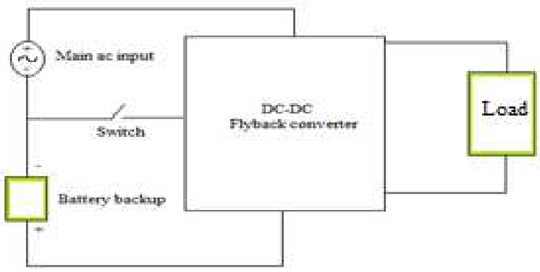

Figure 14: Fly Back Converter Integrated with Battery Back-up

The simulink diagram of Integrated Fly back converter with low battery back-up is shown in Figure 15.

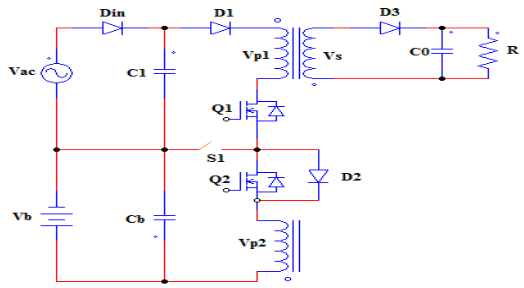

Figure 15: Simulink Diagram of Integrated Fly Back Converter with Battery Back-up

The states of switch Q1, Q2 and S1 in Figure 15 is shown in table 1. From table 1, it can be understood that when a power failure is detected, Q1 is switched off and immediately the switch S1 is closed and the mode of operation of circuit changes from normal to back-up mode. In the back-up mode, the load will be supplied power from the low voltage battery.

Table 1: States of SWITCH S1 and Transistors (Q1, Q2) in All Three Modes of Operation

	Normal Mode	Charging Mode	Backup Mode
Q1	ON	ON	OFF
Q2	OFF	-	ON
S1	Closed	Open	Closed

The condition to be satisfied during the operation of circuit is given below:

$$V_{D3\,(backup)} > V_{D3\,(normal)} > V_{D3\,(charging)} \quad (10)$$

$$D_{2\,(backup)} < D_{2\,(normal)} < D_{2\,(charging)} \quad (11)$$

SIMULATION RESULTS

Simulations were carried out by cutting of input supply voltage from 0 to 0.05 sec by using a switch triggered by a step signal implying that the power supply is given by V_{ac} only during 0 to 0.05 seconds which is shown in Figure 16

.From the figure, it can be seen that the load is being supplied by the low voltage battery back-up in the absence of V_{ac} ensuring uninterruptible power supply to the load.

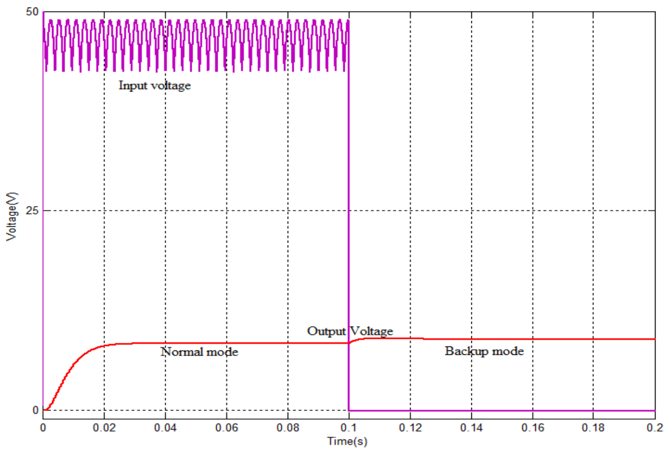

Figure 16: Output Voltage and Input Voltage versus Time during Normal Mode (0 to 0.05 Sec) and Backup Mode (0.05 to 0.1 Sec)

This proposed converter has the advantage of High conversion efficiency, Simple magnetic circuit, Low cost and small size. It is highly reliable when compared with other SMPS circuits.

HARDWARE RESULTS

The experimental set up for the fly back converter for LED lighting is shown in Figure 17. The experimental setup includes isolation transformer for protection, variac for varying the input side voltage to check voltage and current regulation, a fly back converter and LEDs. The main advantage of this circuit is that both voltage and current regulation is obtained with a single and simple circuit. And also as self driven SR is used, the necessity of additional gate driver is avoided, thus contributing to high power density and simple circuit.

The overall hardware setup is shown in Figure 18.

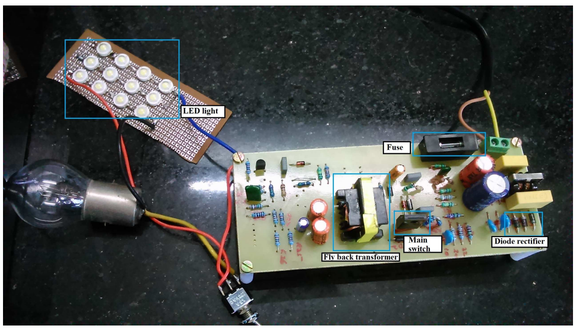

Figure 17: Experimental Setup of Fly Back Converter for LED Lighting Applications

Table: 2 Description and Part Number of Significant Components used

Description of Components	Part Number
Quasi-Resonant Fly back Green Mode Controller	UCC28610D
Secondary-side Synchronous rectifier controller	UCC24610D
Precision Adjustable Shunt Regulator	TL431AIDBZ

Certain significant components used in hardware implementation which add to the advantage of fly back converter are given in table 2.Overall hardware setup with LED lighting is shown in Figure 18.

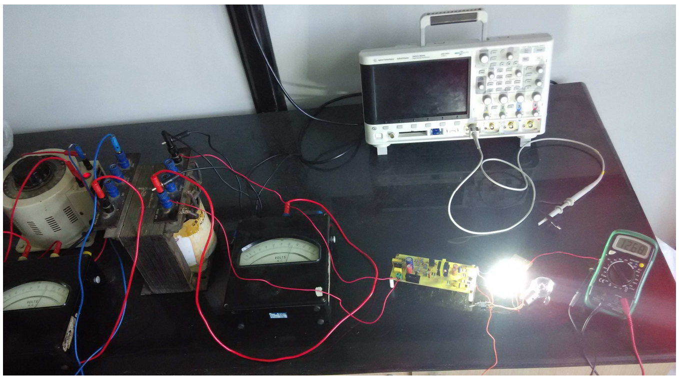

Figure 18: Overall Hardware Setup

CONCLUSIONS

Thus a simple isolated converter which is suitable for a large number of applications such as High power factor applications, LED lighting applications, multi output applications and reliable switched mode power supply applications was discussed and the simulation results were shown. And the hardware implementation of Fly back converter for LED lighting is also shown and discussed. Other than the discussed applications, it has other number of applications which includes Charge controlled devices (CCD) and hybrid electric vehicles. This fly back converter has the advantage of simple magnetic circuit and hence compactness.

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